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THE BOTANICAL REVIEW

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A GUIDE TO THE LITERATURE ON ECOLOGY AND LIFE HISTORIES OF THE ALGAE

G. W. PRESCOTT

Michigan State University, East Lansing, Michigan

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I. INTRODUCTION

Life histories of the algae provide a field of phycology in which studies have yielded and long will continue to yield significant rewards. Investigations of life cycles, as with other aspects of biological science, quickly ramify. The obvious result of these divarications is that such other areas of phycology as culture, ecology and limnology, physiology, taxonomy and cytology become involved. The primary contributions from life history studies have been clarification of taxonomy and the development of ideas concerning phylogeny and evolution. Secondarily, life history and reproduction in relation to time, and the regulating factors have a bearing on limnological and oceanographic problems, upon other sciences and upon various fields in which Man is interested, such as effects of algal growths on biota.

In this outline an attempt is made to present examples of the kinds of ecological and life history studies which have been made, and to indicate what might be done in these fields of phycology.

It is more difficult to outline a single pattern of investigation in ecological life history studies generally applicable to the algae than for such divisions of the plant kingdom as the Bryophyta, Pteridophyta and Mycophyta. This is true because "algae" comprise seven phyla (Divisions), each with its morphological and physiological characteristics (Pascher, 47), if not peculiarities. Thus different approaches are required, and no one scheme of study can apply throughout. This will be taken into consideration in the outline below. Consequently, because literature dealing with the ecology of the "algae" is tremendous in volume, only selected and representative references to pertinent works can be mentioned and listed.

A. Division Chlorophyta[1] (Green Algae)

These are plants of both marine and fresh water, but they occur also in terrestrial and subaerial habitats. Pigments are confined to chloroplasts and include chlorophyll-a and -b, besides three carotenes and as many as four xanthophylls. Food reserves accumulate as starch, usually around a proteinaceous body, the pyrenoid, which, however, is not present in all species. The cell wall involves an inner layer of cellulose and an outer variable layer of pectose. Motile cells, either vegetative or reproductive, have flagella of equal length and are anterior in origin.

B. Division Chrysophyta (Yellow-Green Algae)

This division (Pascher, 716) includes both marine and freshwater organisms, more families and genera, although not species, occurring in the latter medium. Subdivisions are the Xanthophyceae (Heterokontae of some authors), Chrysophyceae, mostly motile, and Bacillariophyceae (diatoms). The pigments are contained in chromatophores, in which chlorophyll seldom predominates, but, instead, carotenes together with an abundance of at least one xanthophyll. Food reserves accumulate as oil and/or leucosin, but pyrenoids are usually lacking. The cell wall is rarely of cellulose but is composed of pectose with silicates often present in varying amounts. The diatoms especially have the cell walls composed of silicates. Motile cells (sometimes amoeboid) are usually equipped with two flagella of unequal length, or they may be uniflagellated.

C. Division Phaeophyta (Brown Algae)

These (almost entirely if not completely marine) vary in size from microscopic filaments to the giant kelps of the Pacific Ocean. The pigments are contained in chromatophores, six xanthophylls, especially fucoxanthin, being the most abundant. Chlorophyll-a and carotene-B are also present. Food reserve is in the form of carbohydrates, such as laminarin, and as soluble alcohol. Cell walls are primarily of cellulose, but plants in general are highly

[1] Papenfuss (126) has suggested the terms "Chlorophycophyta", "Rhodophycophyta", "Phaeophycophyta", etc., recommended in the International Rules of Botanical Nomenclature, 1954.

mucilaginous. Motile reproductive cells are equipped with two laterally attached flagella.

D. Division Rhodophyta (Red Algae)

This predominantly marine phylum, with about a dozen genera in fresh or brackish water, has chromatophores in which r-phycoerythrin is the most abundant. Other pigments include r-phycocyanin, chlorophyll-a and -d, carotene-a and -B, and the xanthophyll, lutein. Plants vary in size from microscopic to macroscopic, some being up to a meter in length. Because of their pigmentation, some forms are able to carry on photosynthesis at abysmal depths. Food reserve is mostly a solid carbohydrate, Floridean starch. Motile vegetative and reproductive cells are lacking. This group is further characterized by its highly complex sexual reproductive processes and diverse life cycle phases, although many genera have a simple life history.

E. Division Euglenophyta (Euglenoids)

This is a phylum of unicellular, motile and protozoan-like organisms, bearing one to four flagella, which, except for a few uncertain forms, exist in fresh water. The majority are pigmented, having cloroplasts and pyrenoids. Chlorophyll-a predominates, but carotene-B is also present, and questionably a xanthophyll. Food reserve is in the form of a solid, starch-like carbohydrate, paramylum. In the main, the cells are naked, except in the Colaciales, there being no cell wall but a periplast which is a differentiated outer boundary of the cytoplasm, often striated. This is either rigid or flexible, according to genus and species. In a few genera there is an exterior lorica of firm gelatinous substance, but cellulose is lacking.

F. Division Pyrrhophyta[2] (Dinoflagellates)

This phylum includes a great diversity of mostly pigmented and, in the main, mobile unicellular organisms. They occur in fresh and in salt water, especially the latter where a few are colonial and some are unpigmented. They possess chromatophores in which brown pigments predominate: carotenes, peridinin and

[2] Pascher (716), in the original use of this term, employs this spelling rather than Pyrrophyta of most authors.

other xanthophylls, with chlorophyll-a and -c also present, particularly the former. Food reserve occurs as both oil and as starch. Characteristically there are two laterally attached flagella. Whereas some cells are naked, most forms have a wall which in some instances at least is of cellulose with an outer pectose layer. The wall may be plain or constructed of plates (armored or thecate dinoflagellates). Although often treated as protozoan, this group possesses many plant-like characteristics, and in at least one genus the vegetative expression is that of a branched filament.

G. Division Cyanophyta (Blue-Green Algae)

Pascher (47) and lately others have excluded these plants from the "algae" and have assigned them to a place with the bacteria in the Schizophyta. They are all microscopic, although in masses and in colonial associations they become macroscopically evident. The Cyanophyta, when compared with other algae, are characterized by their lack of chloroplasts and chromatophores, their lack of a definite nucleus, by their lack of motile cells, and by their lack of sexual reproduction. Pigments are in solution, occurring mostly in the peripheral region of the cell, and are extremely variable throughout the group. Whereas chlorophyll-a may predominate, it is more often masked by carotene-B, flavicin, by two xanthophylls (myxoxanthin and myxoxanthophyll), or by c-phycoerythrin and c-phycocyanin, the latter often abundant and accounting for the name, blue-green algae. Food reserves are mostly glycogen, but there is a question as to the true nature of this carbohydrate.

H. Divisions of Uncertain Position

The chloromonads (green) and the Cryptophyceae (yellow-brown or blue) are pigmented, protozoa-like unicells which have no clearly recognizable Division status. (See Fritsch, 18; Pascher, 715; Pringsheim, 752; Smith, 63). They are mostly from fresh or brackish water habitats. The chloromonads (*Gonyostomum*, e.g.) might well constitute a separate Division because of their unique characteristics. The Cryptophyceae sometimes are placed as a class within the Pyrrhophyta because of their somewhat similar pigmentation and type of flagellation.

Useful works of a general nature which deal with the taxonomy and classification of the fresh-water algae are listed separately in the bibliography A.

II. ECOLOGICAL CLASSIFICATION OF ALGAE

Before listing somewhat in detail the various types of ecological studies which have been directed toward the several Divisions of the algae, it is appropriate here to summarize ecological classifications of "algae" and to indicate the general approaches to be followed in life history investigations.

A. According to Their Position in Water, and the Amount of Water in Their Habitat

1. AQUATIC.

a. Planktonic. Very many genera in several Divisions are entirely drifting (euplanktonic) in the open water of seas, ponds and streams. The entire life history is passed in this situation, although spores or other resting and reproductive elements may be temporarily sedentary. Studies require periodic qualitative and quantitative collections (net or plankton trap) to determine reproductive periodicity in nature, accompanied by laboratory culture for spore germination, life history stages, cytological investigations of meiosis, and chemical-physical analyses of water habitat.

b. Tychoplanktonic. Whereas some forms exist only in open water, many more occur in shallow water near shore, intermingled with aquatic vegetation or may form floating mats, especially in fresh-water ponds and lakes. Periodic collections by drag-net, pipette, or by hand. Laboratory culture for spore germination. Chemical analyses of water; tests for growth-inhibiting or growth-promoting substances as possible regulators in life history stages.

c. Benthic.[3] Although limited by such factors as light and gas-content, some algae can live attached in deep water (40–200 feet) and hence must be dredged. Chemical analyses of water; measurement of light penetration by photo-electric cell; temperature readings by reversible thermometer or by electrical device; laboratory culture for growth and reproductive stages; experiments with

[3] Referring here to habitats below the usual photosynthetic zone, i.e., more than 15 feet below the surface.

light of different wave-lengths in relation to incidents of reproduction. Eckman or other type of dredge and core samplers for taking of deep-water specimens.

d. Attached and Littoral. Algae representing several phyla occur at or near the shore line on rocks or other submerged strata in shallow water (littoral-benthic). Many marine algae (lithophytes) accordingly find themselves existing half of the time as terrestrial plants because of tide action. Others occur as incidental or specific epiphytes. In fresh-water habitats a somewhat indefinite ecos exists about floating or emergent vegetation at the water line (periphyton). Life history studies require periodic collections and floristic records, mapping and satistical analyses of quadrats; succession on artificially or naturally denuded strata; detection of reproductive stages in reference to tides and lunar cycles; water temperature; salinity; light intensity; laboratory studies for germination of spores; germling stages and phases in the alternation of generations, accompanied by cytological studies.

e. Hot water (Thermal Habitats). Particularly the Cyanophyta exhibit an ability to live either in water of average temperature or as thermal algae in water only slightly below the boiling point. At the same time there is a flora definitely related to hot-water habitats. Collections are made periodically with net and scraping tools, and isolates are cultured in the laboratory under conditions which must be determined experimentally as suitable in respect to media, temperature and light.

2. SUBAERIAL, TERRESTRIAL, CRYOPLANKTONIC

a. Subaerial. Although many algae found in subaerial habitats may occur also in aquatic situations, not a few are definitely related to a terrestrial existence, on and in soil, and on dripping banks or on the trunks of trees. Humid regions of the tropics and subtropics favor the occurrence of more species of subaerial algae than do latitudes remote from the equator.

b. Psammon. Not clearly defined but highly productive of algae and other microorganisms is the sandy beach zone. Just beneath a thin layer of sand a profuse growth occurs in which there are many species, mostly Chlorophyta, Cyanophyta and diatoms, not necessarily found in the plankton of the nearby aquatic environment. Life history studies involve collection of sand, washing and

culturing in the laboratory for floristic analysis and for a study of stages in the alternation of generations.

c. Cryoplanktonic. A few members of the Volvocales, especially *Chlamydomonas,* Chlorococcales and Dinophyceae occur in polar and alpine stations where they produce green, red and yellow snow. Some of the desmids also occur in permanent ice fields of the far north and in the loess and morainic material on the surface of glaciers. Living in a medium which consists of a film of water only slightly above zero degrees C., these organisms are physiologically adjusted to an existence at low temperatures and in strong illumination. Furthermore, a few genera occur in or under ice in lowland lakes of temperate latitudes, e.g., *Oscillatoria* spp., *Aphanizomenon flos-aquae, Vaucheria sessilis* var. *sericea,* the latter having been found in a reproductive state in pockets of ice during winter months in Iowa.

A study of life histories involves the collecting of unit samples of soil, snow or ice with sterile instruments. Special media must be determined experimentally, and particular nutrients must be provided for any nitrogen-fixation investigations. Field records must include temperature readings, pH and other chemical analyses of the natural habitat to determine the factors which are related to or which induce reproductive phases.

B. According to Chemical Composition of the Water

1. HALOPHYTIC. All Divisions of the algae have representatives in both fresh and salt water, although in the Euglenophyta there are but few marine forms and some of these are questionable. Conversely, there are very few Phaeophyta in fresh water. Only very seldom is the same species found in both types of habitats, but not infrequently facultative or brackish-water forms occur. The composition of sea water, especially the concentration of sodium chloride, exerts a tremendous selectivity, particularly upon numbers of kinds of organisms. Most marine species occur when the concentration of sodium chloride is three to four per cent, or when total salts are 35 gm. per kilogram of sea water. Variation of salt content has a more pronounced effect on the amount and distribution of phytoplankton than upon attached seaweeds. For life history and ecological studies, periodic collections must be made, accompanied by chemical analyses of the water.

2. CALCIPHILIC (ALKALINE HABITATS). High pH (above neutrality) is usually associated with dense concentrations of dissolved nutrients. Hence hard waters are producers of profuse algal growths, particularly in fresh-water habitats and especially if they have been enriched by nitrogen and phosphorus. Such growths are also made possible by attending high reserves of CO_2 necessary for plant metabolism. In fresh water there is a calciphilic algal flora, known as the " Baltic type " in which diatoms and blue-green algae predominate. The life cycle of some calciphilic species varies from that of soft water or calciphobic species. For a study of the life history, periodic quantitative and qualitative collections are made to determine periodicity of reproductive stages and succession of dominant species.

3. CALCIPHOBIC (ACID HABITATS). In contrast, waters with a low pH are soft and lack high concentrations of nutrients, the " Caledonian type " of habitat. Hence soft water lakes and bogs, in which shallow or marginal waters become enriched with organic acids and nutrients resulting from decomposition of organic matter, may support a calciphobic flora. Such a flora, principally desmids and an association of certain blue-green algae (*Hapalosiphon fontinalis, Stigonema ocellatum, Chroococcus turgidus*), may be rich both in quantity and in number of species. But whether the rich desmid flora is related to the lack of calcium or to the presence of growth-promoting nutrients in the decomposed organic matter is not known precisely. Periodic and year-around collections by plankton net; by moss squeezings, etc. followed by culture studies are needed to determine reproductive and life history stages. Special culture media are required for desmids and other Conjugatae, together with experimental methods to determine conditions which will induce sexual reproduction.

4. GEOLOGICAL FACTORS. Obviously the chemistry of the water habitat is directly related to, and for the most part determined by, the physico-chemical nature of geological formations. The underlying rocks, together with the chemistry of the soil through which water passes or over which it collects, determine the composition of solutes in the aquatic environment and help to determine the Caledonian, or the Baltic lake. The sea itself of course is such a milieu of soil extractions. Geological formation has a bearing not

only on soluble nutrients but also on the physiology of inhabiting organisms in other ways. Tropical and subtropical waters, for example, which in some respects are favorable for a rich algal flora, may be sterile because of the amount of suspended matter that in turn is determined by the physico-chemical nature of tropical soils and meteorological conditions near the equator. Ancient or igneous rock formations determine soft or acid water habitats in contrast to basic waters resulting from drainage through sedimentary rock, especially limestone. Hence ecological studies of aquatic organisms may require that physiography and geology be considered.

C. According to Relationships with Other Organisms

For the most part, culture studies in the laboratory are required in order to investigate life history phases, although much can be learned through repeated and patient collections throughout all the year.

1. EPIPHYTIC. Whereas algae, both marine and fresh-water, may be incidentally attached to other plants as well as to a variety of aquatic subtrates, there exist not a few forms which are ecologically related to specific hosts. In fresh water the hosts are usually among the so-called higher aquatic plants, although many species are found growing on other algae, whereas marine species have few plants on which to become attached, except to other algae. In making life history studies of epiphytes and endophytes it is necessary to consider the ecology and growth stages of the host, and laboratory studies may involve culturing of the host as well as the attached forms. A few algae are epizoic or endozoic.

2. ENDOPHYTIC. Epiphytes on terrestrial plants are usually, in part, endophytic, whereas aquatic algae may be strictly endophytic. There are examples of specific endophytism among both aquatic and subaerial algae. Life history studies have been successful for many in respect to the reproductive methods, but little is known concerning the precise factors which determine specific selection of host. An investigation of endophytism in higher plants requires frequent and periodic collection of material, and sometimes the growing of host plants in greenhouses if either physiology or life history is to be understood. In both marine and fresh-water algae

the endophyte may select a wide range of hosts, usually somewhat related, or many occur only in particular and unrelated species.

3. PARASITIC. Epiphytes and endophytes may induce pathological conditions in host plants. Especially colorless algae may be regarded ecologically as parasites or hemiparasites inasmuch as all or a major part of their sustenance is obtained from the host. Culture studies are required for investigations of the life history, and highly specialized techniques must be employed in order to maintain the parasitic relationships under artificial conditions.

4. COMMENSAL. Another type of symbiotism exists in which an exchange of benefits apparently occurs. Lichens, in which parasitism also may be involved, exhibit such a symbiotism as does the relationship between root-inhabiting or thallus-inhabiting algae and *Cycas*, *Lemna*, *Riccia*, etc.

III. RELATIONSHIPS IN ALGAL ECOLOGY TO BE CONSIDERED

Studies in life histories and ecological adaptations are undertaken with a number of determiners under consideration. Perhaps the most important factors are:

A. Light

Quantity; quality; periodicity; seasonal duration; relation of algae to depth of the aquatic medium or the position in a subaerial environment; altitude and latitude of the habitat; specific requirements for various wave lengths; lunar radiation; light intensity and/or duration in relation to changes in the life history.

B. Gases

Quantity and quality at different depths in the aquatic medium; relation of gases to water temperature and saturation coefficients; altitude and atmospheric concentrations; specificity of algae for differing concentrations in the water medium; relation to diminished oxygen and initiation of reproductive phase.

C. Nutrients

Quality and concentrations of nutritive elements or substances; specificity and optimum supplies of critical elements (optimum

amounts of N, P, K, Na, etc.) for growth; relation of amounts to stages in the life cycle; micro-nutrients; induction of dormancy.

D. Temperature

Optimum, maximum and minimum temperatures permitting metabolism, or possibly in determining reproductive processes.

E. Tides and Currents

Physical effects, and more importantly the relationship between water movement and other factors such as nutrients (availability), temperature (changes), availability of gases, rythmic movements of water in relation to reproductive and vegetative phases in the life cycle, initiation of zoospore- and gamete-formation in relation to tides and lunar cycles.

F. Antibiotics and Growth Promoters

Inhibiting and growth- and reproduction-promoting substances produced by some algae, or by other plants which have a direct bearing on algal distribution and which determine presence or absence of species, or which determine growth quanta, time of reproduction, initiation of growth period, etc. (algaphage).

IV. RELATIONS OF ALGAL ECOLOGY TO OTHER SCIENCES

Objectives of life history studies have bearings on other fields of biology and natural science quite aside from contributions that such pursuits might make to phycology as such.

A. Limnology and Oceanography

Because of the interacting of the biota and the physical-chemical features of waters, life history and ecological studies are closely integrated in limnology and oceanography. In fact, hydrological studies are carried on more often than not with the gaining of knowledge of production of plant and animal life as the chief objective.

B. Fisheries and Shell-Fish Culture

The direct bearing that algae and algal products have on the food cycle of aquatic animals necessitates a consideration of algal

ecology and stages in the life cycle. Furthermore, the distribution and composition of the algal flora are related to other problems concerned with aquatic animals such as breeding, nesting habits and shelter.

C. Paleontology

The fossil remains of algae and their distribution in time and space are of interest to the general geologist, but especially to the petrologist and paleontologist. Ecological studies of present day algae throw light on their distribution in the past and aid in constructing pictures for the historical hydrologist.

D. Soil and Water Fertility

Nitrogen-fixation by both soil and strictly aquatic algae is important enough so that there is a call for ecological studies of species possessing this capacity. Physiological experimentation indicates that the role of algae in the formation of nitrates may be of greater significance than has been accorded them (Fritsch and De, 420; Henricksson, 483; Williams and Burris, 964).

E. Water Supplies and Water Sanitation

The economics of algal ecology is brought to the fore in problems involving the spoilage of water for domestic and industrial use, especially water supplies of larger cities. The distribution of algae, stages in their life cycle, their relationship to water chemistry and other ecological factors become involved in control measures. Research is continuing in an effort to determine algal and protozoan species which can be used as index organisms of pollution (Lackey, 601; Brinley, 239).

F. Pathological: Death of Animals

Objectionable algae may cause illness or death of fish, both marine and fresh-water, and death of domestic animals and fowls. Enteritic epidemics in man have been traced inconclusively to toxic species of algae. More information is needed to relate such harmful effects to stages in life history. Efficient control measures or eradication are worked out only through a consideration of algal ecology and the composition of the algal flora as determined by factors influencing growth, life history and the distribution of specific forms.

G. Industrial, Commercial and Other Economic Aspects

The ecology of several species of marine algae is related to the problem of supply of products used in commerce and in pharmacy. Location and relocation of beds of plants used industrially and the repopulation of denuded strata bring up ecological problems involving life histories of the algae in question. The use of algal gels and alginates is increasing as is the use of marine species in foods and fertilizers (Scottish Institute of Seaweed Research, where ecological investigations are conducted exhaustively).

H. Scientific and Medical Research

The past decade has seen the use of algae in culture for the assay of biologicals (Hutner, 507; Hutner and Provasoli et al., 509), and in physiological studies related to cancer research (Chas. F. Kettering Foundation), all involving problems of an ecological nature.

V. TAXONOMY

As a basis for ecological studies, the student is required to confer with taxonomic treatments of respective groups. There are few such works which deal systematically with more than one Division, subdivision or Order. Some of the literature of a general nature, or monographs which are useful, are listed in the Bibliography A, B. Unfortunately the list of shorter but highly valuable taxonomic studies is so exhaustive as to prevent inclusion.

VI. THE LITERATURE

A. Fresh-water Algae

1. LIFE HISTORIES, PHYLOGENY AND CULTURE. Life history studies are best carried on, or at least are usually made conclusive, by laboratory culture. During the past 15 or 20 years the culturing of algae has been brought to bear upon many biological and economic problems. Consequently algal cultures have achieved great importance, techniques have been refined and an enormous literature has accumulated, with publications appearing in a continuous stream. The papers which relate directly to life histories are not so numerous as those which deal with physiology, metabolic products and taxonomy. Below are listed a few selected works which deal with life histories and reproduction of fresh-

water algae, or which, because they give useful information on methods, are pertinent for one who might wish to pursue ecological studies. In this and in subsequent lists many citations bear on overlapping subject matter, but an attempt is made to classify them according to the chief topic.

a. Techniques and Media.
   a. General and Classical Studies: 199 (*Zoochlorella*; Lichens); 200 (unicellular Chlorophyta); 201 (media); 301 (technique); 584 (culture methods).
   b. Pure Culture Methods as Applied to Genera; to Desmids: 223 (Chlorophycean & Euglenophycean; media composition); 610 (Desmids); 749, 750, 751, 752, 753 (culture methods applied to different algal groups).
   c. Nitrogen-fixation: 738 (soil); 819 (soil). (Also see Pure Culture and Isolation, *sq.*)
   d. Nutrients: 785 (nutritional requirements): 884 (nutrients from bottom sediments).
   e. Scientific Research: 652.

b. Pure Culture and Isolation.
   a. Light Relationships: 148 (artificial light); 226 (intensity and *Chlamydomonas*); 228 (pigmentation, Cyanophyta); 244 (soil); 347 (quality and *Chlamydomonas*); 430, 431 (pigmentation); 469, 470, 471 (pigmentation and physiology); 653 (colony formation).
   b. Culture of Genera to Determine Ecological Factors as Related to Reproduction and Life Histories: 188 (*Chlorella*); 298 (*Scenedesmus*, et al.); 403 (*Oedogonium*); 441 (*Peniocystis*); 442 (*Microcystis*); 541 (*Vaucheria*); 583A (Chlorophyta); 587 (*Chlorochytrium*); 756 (*Euglena*); 788 (*Aphanizomenon*); 814 (*Oscillatoria*); 983 (*Pandorina*).
   c. Classes and Families in Culture: 147 (Cyanophyta); 177 (Dinoflagellatae); 362 (Euglenoids); 403 (Chlorophyta, reproduction in *Oedogonium*); 440, 441 (Cyanophyta); 507 (Euglenoids); 863, 864, 865 (Chlorophyta, Desmids); 962 (Diatoms).
   d. Growth Substances: Antibiotics: Assay of Biologicals: 235; 509; 584; 756.
   e. Sexuality and Reproduction: 402 (asexual and factors

involved); 559 (sexuality); 863, 864, 865 (Desmids and genetics).

f. Ecological Factors (General); 421 (soil); 653 (colony formation); 783 (soil and use of carbon compounds); 814 (pigmentation); 973, 982 (plankton).

2. REPRODUCTION AND LIFE HISTORIES.

a. Soil and Nitrogen-Fixation. Ecological interest in soil and subaerial algae takes several directions; as possible origin of the land flora; succession of floras in terrestrial habitats; general physiology of plants; nitrogen fixation. In respect to the latter there have been many studies which have indicated the importance of especially blue-green algae in soil fertility. Although this aspect of algal ecology has been studied since late in the last century, much still remains to be learned and explorations are still in progress.

It is apparent that some species of algae are as important in the nitrogen cycle as are soil bacteria. Representative studies on nitrogen-fixation and related ecology concerned with life histories are:

a. General Studies: 736 (Denmark); 784 (soil algae in Colorado).

b. Nutrients and Factors Related to Nitrogen-Fixation: 153; 155; 783.

c. Bacteria and Symbiotic Relationships: 230; 483 (*Collema*); 678 (historical interest); 607 (historical comment on 678); 689; 773 (*Volvox*).

d. Genera and Algal Classes: 154 (*Nostoc*); 245 (Chlorophyta, negative results); 340 (Cyanophyta in rice fields); 400 (Cyanophyta, with some negative results); 420 (Cyanophyta); 483 (*Nostoc*); 580 (Chlorophyta); 819 (Chlorophyta, negative results); 946 (green plants); 964 (Cyanophyta).

b. Subaerial and Soil Algae. (See also Soil and Nitrogen-Fixation). The literature on subaerial and soil algae is composed mostly of descriptive studies and taxonomic analyses. A tremendous amount of work is needed in the way of micro-climate analyses to determine cause-effect relationships within the correlations that often appear between components of the biota and conditions in

the subaerial environment. Much has been written, however, on soil algae in various parts of the world, such as studies in respect to succession, and by way of description, whereas less has been published on life histories of subaerial algae.

a. Culture of Soil Algae: 233 (morphological changes); 242 (use of carbon compounds); 244 (light relationships); 400 (Chlorophyta and Cyanophyta); 410 (moisture relationships); 421 (morphology); 630 (general investigations, Canada); 670, 672 (subterranean); 738 (taxonomy and culture soil algae); 783 (relation to soluble carbon compounds); 784 (soil algae, Colorado).

b. Ecology: Ecological Factors Related to Soil Flora: 227 (succession); 241 (dormancy); 375 (soil and lithophytic); 391 (desert rain crusts); 406 (succession); 409 (Chlorophyta); 410 (moisture relations); 415 (succession); 421 (ecology and morphological adaptation); 422 (floristic); 426 (ecology and succession); 444 (Cyanophyta in soil); 522 (soil associations); 525 (microstratification); 574 (ecology *Botrydium*); 670, 672 (of subterranean flora); 736 (Denmark); 737 (Iceland); 784 (Colorado); 815 (ecology aerial).

c. Diatoms in Soil: 189; 634; 670; 672.

d. Aerial: 268; 407, 658 (tropics); 736 (Denmark); 737 (Iceland); 815 (ecology); 934, 935 (epiphytic in tropics).

e. Snow-Ice: 194 (Greenland); 408 (Orkney Islands); 429 (see 503, the same); 434 (Antarctic); 464A (ecology of green snow flora); 503, 564, 565 (Japan); 570 (Switzerland); 571 (floristic); 571A (physical and chemical ecological factors, pH and sunlight); 571B (geology in relation to cryoplankton); 572 (Yellowstone); 573 (Alaska); 602 (Andes); 886 (Dinoflagellates in snow); 972 (Greenland).

c. Limnology and Algal Ecology. The quantity and quality of algal floras in fresh-water habitats and seasonal variation in composition (sometimes amounting to a more or less regular succession) are directly related to limnological features. In these connections limnology and algal ecology are closely integrated and the mountainous literature attests to the interrelationships. Pub-

lished works suggesting approaches to limnological problems for life history studies are exemplified by:

a. Limnological Factors: 52 (general considerations); 169 (seasonal changes); 176 (plankton control); 183 (gases); 190, 205 (thermocline and gases); 206 (in New York lakes); 207 (organic content); 234 (production in North Dakota lakes); 252 (production in New York lakes); 272, 273, 274 (Lake Erie); 294, 295, 296 (Swiss lakes); 303 (Lake Nipigon); 310, 311 (phosphorus and nitrogen); 326 (Lake Michigan); 351 (ammonia and nitrates); 352 (nitrogen); 425 (production and succession); 443 (thermocline and vertical distribution); 459 (production and plankton composition); 473 (Texas artificial lakes); 536, 537 (phosphorus); 538 (gases and pH); 575 (tropical waters); 588 (pH); 631 (plankton distribution); 637 (production); 656 (Japanese lakes); 677 (Louisiana lakes); 679 (nitrogen); 693, 695, 698 (pH and other factors related to production); 725 (glacial lakes); 727 (English lakes); 728, 729 (nutrients and plankton production); 739 (nitrogenous compounds); 764 (calcareous lake); 765 (pH, calcareous and granitic lakes); 777, 786, 787 (composition of lake waters); 825 (production of plankton); 877 (Characeae); 880 (pH and habitat classification); 882, 907 (production); 922 (Ontario lakes); 923 (New York lakes); 924 (Wisconsin lakes); 925 (Ohio lakes); 939 (production); 950 (dissolved substances); 951, 952, 953 (Michigan lakes); 960 (gases); 963 (quality and quantity of plankton); 981 (Ohio lakes); 994 (Montana).

b. General Considerations: 52 (in Great Lakes region); 342 (geographical aspects of limnology); 369 (aquatic ecology); 693, 696 (ecological problems); 697 (nomenclature); 698; 727 (English lakes); 732 (geological); 789 (soils and geological aspects of production); 853 (conditions determining distribution); 883 (Norwegian lakes); 907 (limnological factors and production; excellent paper); 981 (production in Ohio lakes); 1001 (brackish water, Belgium).

c. Plankton Measurement: 578 (chlorophyll extraction); 646 (pigment evaluation); 778.

d. Diatoms: 316 (Wyoming); 485 (periodicity); 586 (limnology of diatom production).

e. Physiology: 791.

f. Periodicity: 169; 425; 777.

g. Light. An important factor in the ecology of algae (usually considered in limnological studies), and one which is limiting or determinative in the life history of many species is that of light. Not only do light intensity and penetration have important roles, but also diurnal and seasonal periodicity. Light in polar regions, for example, presents a much different series of problems than it does in lower latitudes where day and night are nearly equal throughout the year. Pertinent publications on light and its bearing on physiology and ecology are: 168 (measurement); 226 (intensity and *Chlamydomonas*); 228 (pigmentation); 347 (*Chlamydomonas*); 376 (measurement); 430, 430A (Oscillatoriaceae); 431 (pigmentation); 539 (intensity of penetration at different depths); 645 (photosynthesis); 653 (colony formation); 731, 733, 734 (penetration); 817 (photosynthesis).

d. Streams and Stream Ecology. Ecology of stream algae, their distribution and periodicity require a somewhat different procedure than employed in strict limnology. Whereas year-around collections and chemical samplings are made as in the study of lakes, a survey of streams must be extended horizontally along the course, and stations (often widely separated) must be established.

It is of interest not only to determine the composition of the biota in relation to the physical-chemical properties at different positions in the stream, but also to determine the fate of organisms as they are carried from lakes, bogs, or springs at the origin. Whereas life history studies of stream algae may be carried into the laboratory, many, if not most species that are characteristic of flowing water do not lend themselves well to culture. Attached species of *Cladophora, Rhizoclonium, Vaucheria, Lemanea, Batrachospermum, Hildenbrandia, Nostoc,* and others defy culture, or require particularized procedures and media.

Representative studies in stream ecology include: 240 (plankton); 246, 250 (periodicity); 251 (ecological features); 255

(benthic); 270, 271 (lake plankton in stream); 318 (pH); 366 (succession); 392, 393, 394, 395 (Diatoms); 517 (Zygnemales and stream classification); 521 (succession); 568, 569 (quantitative biota); 769, 823, 824, 890 (general stream ecology).

e. Psammon and Periphyton. An area of limnology on which very little work has been done is the psammon and the ecology and the life histories of the organisms which comprise it. This aspect of limnology by nature falls as well to the ecologist interested in soil algae. Likewise the periphyton habitat and the life history of the algal components has been neglected apparently. Helpful studies are: 700 (Michigan lake); 862 (eutrophic lake); 993 (periphyton).

f. Distribution. Ecological studies such as those mentioned above lead toward or include also distribution of algae and their life history as related to distribution. This aspect of ecology can not be separated from floral composition in relation to habitat factors. Especially our knowledge of geographical distribution must come from digesting and synthesizing of published accounts from many areas, and by comparing systematic lists which are accompanied by habitat data. Unfortunately, the majority of taxonomists are satisfied by listing of specific names without presenting pertinent ecological information, and a pattern of distribution is often little more than a pattern of collection points.

Examples of studies which deal with either local or geographical distribution of fresh-water algae are:

a. Geographical: 317 (reference to geology): 353, 367 (general considerations); 387 (and periodicity); 818; 866, 879 (glaciation); 881.

b. Factors Related: 210 (general); 367 (general); 370 (light and temperature); 631 (vertical distribution); 692 (iron and other factors); 765 (calcium and pH); 853A (general); 931 (gases and pH); 932 (iron and other factors); 938 (pH).

c. Local Studies: 156 (Haute-Marienne); 158 (British chalk cliffs); 159 (sand hills Nebraska); 452 (Lake Windemere); 458 (British lakes); 631 (vertical distribution); 657 (North Dakota); 709 (Arctic lakes); 721 (vertical and horizontal distribution); 730 (horizontal distribution); 936 (Congo); 1001 (brackish water, Belgium).

d. Thermal: 231; 312 (Yellowstone); 401 (France); 468 (Bohemia); 701 (Japan); 878 (Spitzbergen); 913 (U. S.); 941, 942, 943 (origin and development of thermal flora); 954 (taxonomy); 989 (Japan); 996 (Russia).

e. Algal Groups: 388 (Characeae); 516 (fresh-water Rhodophyta); 606 (Desmids); 722 (Diatoms); 741 (currents, *Rivularia* morphology and distribution); 782 (Diatoms); 853 (*Volvox*); 955, 956 (Desmids); 940, 978, 979 (Characeae).

g. Periodicity. A few generalities can be drawn from our knowledge of fresh-water algal periodicity—but very few. Here is a field in which ecologists find a host of opportunities for making contributions. We need to know to what extent periodicity and succession are determined by physiology of the organism and to what extent periodicity is regulated by ecological factors. Ecological studies have been summarized more often than not by delegating causal relationships to merely attending phenomena. Therefore, a closer cooperation between field ecologists, the taxonomists, and the laboratory technicians is demanded. The paucity of information on algal periodicity can be attributed partly to the critical time factor. Few researchers have the opportunity to carry on the necessary long-time and long-range field work—and unfortunately many researchers do not have the inclination and patience. So at present we can turn to but few publications in fresh-water periodicity and such critical reports as we have are often related to a genus or to a particular species—which studies, however, are basic and point the way to additional work.

A few papers dealing with periodicity and succession, and some which illustrate the procedure for ecological work are:

a. General: 149 (succession in forest ponds, not particularly algal); 159; 170 (annual succession); 224 (plankton); 246 (ponds and streams); 257 (in Massachusetts); 307, 308 (succession over 5 years); 317 (in Arkansas); 327A (plankton); 343 (heath algae); 346 (in France); 348 (succession in Minnesota); 366 (general); 404, 405 (British ponds); 423, 424, 425 (British lakes); 426 (succession through 6 phases); 458 (in British lakes); 479 (succession in New York); 485 (development of maxima); 490 (factors determining); 548, 549 (in German ponds);

568, 569 (stream plankton); 608 (German ponds); 611 (and reproduction); 625 (factors controlling); 650 (Scotland); 683 (New York lakes); 725, 727 (British lakes); 759 (German lakes); 837 (in Chile); 879 (and geographical distribution); 916, 917 (succession in bogs; general ecology, not algae); 918, 920 (Illinois lakes); 937 (historical review); 957 (British lakes); 999 (plankton).

b. Genera and Algal Groups: 232 (*Euglena*); 249 (Rhodophyta, Phaeophyta); 313, 328 (*Spirogyra*); 464 (*Euglena*); 485 (Diatoms); 579 (Desmids); 611 (Desmids); 648, 726 (Diatoms); 911 (*Oedogonium*).

h. Alternation of Generations.

a. Culture studies: 293 (unicellular algae); 299 (*Scenedesmus*); 324 (Conjugales); 364 (*Oedogonium*); 559 (reproduction and sexuality); 790 (*Lemanea*); 863, 864, 865 (Chlorophyta, especially Desmids); 958 (relation to taxonomy).

b. Genera and Algal Classes: 149A (*Coleochaete*); 193 (*Spirogyra*); 214 (*Enteromorpha*); 221 (*Chlorococcum*); 222 (*Protosiphon*); 225 (Chaetophorales, *Trentepohlia*); 236 (*Vaucheria*); 263 (Ulvaceae); 269 (Rhodophyta and Chlorophyta); 288 (*Pleodorina*); 299 (*Scenedesmus*); 309 (*Cladophora*); 324 (*Spirogyra*); 325 (Conjugales); 359 (*Pleurococcus*); 363 (*Eudorina*); 397 (*Ulva* and *Cladophora*); 428 (*Prasiola*); 437 (Diatoms); 460 (*Ulothrix*); 467 (*Vaucheria*); 475 (*Chaetomorpha* and *Enteromorpha*); 524 (*Volvox*); 534 (*Hydrodictyon*); 540 (*Stigeoclonium*); 541 (*Vaucheria*); 546 (*Characium*); 547 (*Schizomeris*); 567 (*Vaucheria*); 574 (*Botrydium*); 624 (*Ulothrix*); 626 (*Cladophora*); 639 (*Hydrodictyon*); 640 (*Oedogonium*); 655 (Desmids); 659 (Chlorophyta); 660 (Ulvaceae); 684 (*Vaucheria*); 716 (Diatoms); 719 (*Chlamydomonas*); 755 (*Pediastrum* and *Sorastrum*); 790 (*Lemanea*); 820 (Volvocales); 826 (Desmids and Diatoms); 848 (*Fritschiella*); 855 (*Chlamydomonas*); 857 (all Divisions); 865 (Desmids); 876 (Volvocales); 909 (Chlorophyta); 919 (*Gloeotaenium*); 929 (*Chara*); 934 (*Trentepohlia*); 983 (*Pandorina*).

c. Haploid and diploid generations: alternation: 150, 225,

280, 358 (genetics); 414, 418, 465, 523, 554, 555 (general considerations); 560 (cytology); 609 (taxonomic relationships); 893, 900, 929 (cytology).

3. ASSOCIATIONS. Associations of algae vary from time to time throughout the year, and from year to year. There appear, however, recurrent combinations of algal species, especially in similar habitats. The associations (perhaps more true for marine algae than for fresh-water) are determined in part by the life history stages of the species involved. Among algae, as for other plants, the ecology of communities of species, or of associations (algae with algae, or algae with other organisms) constitute a field in which there may be a complete overlapping and intergradation of physiological and taxonomic studies. There develop, for example, combinations of algal species (somewhat consistently) when any habitat possesses optimum growth conditions, thereby suggesting, if not proving a similarity of physiology and of life history among a number of possibly unrelated species. A consideration of community compositions and related ecological factors quickly ramifies into problems of succession (better understood, however, among marine algae). The matter of association, closely related to community, divaricates when symbiotism (parasitism and mutualism) are considered.

Whereas much useful information has been and can still be gained from field observations and taxonomic analyses, final solutions to these ecological problems and the bearing that life histories have on them, ordinarily must be obtained in the laboratory. This is especially true for such associations as the lichen complex, studies which involve special culture methods and techniques for obtaining pure growths of the components. Notwithstanding all the work which has been done on the problematical relationship between fungi and algae, including their life histories, investigations continue, using highly specialized techniques and media.

The particularized symbiotic relationships between certain species of algae and other organisms (e.g., *Chlorella* and sponge, and *Hydra*; *Nostoc* and cycads; *Chlorochytrium* and *Lemna*) present problems still to be solved. The precise association of *Characium* and animal hosts, *Basicladia* and turtles, *Trichophilus* and the sloth suggest still other problems, as does the exact nature of such algae as *Glaucocystis* and *Gloeochaete*, considered to be a

complex of blue-green protoplasts and colorless Chlorococcalean cells.

Representative studies on the ecology of associations and upon symbiotic relationships of fresh-water algae are:

a. Communities: 163 (general; not particularly related to algae); 189 (Diatoms); 191 (chemical factors related to communities); 208 (with animals); 341 (shore); 368 (plankton); 369 (general considerations); 413 (classification of communities); 444 (Cyanophyta in India); 500 (with animals); 606 (Desmids); 651 (*Cladophora* and *Ulothrix*); 694 (littoral); 742 (water blooms); 767 (with animals); 906 (plankton).

b. Symbiotism.

a. Lichens: 321; 371; 389; 482; 627; 757; 758; 947; 949; 998.

b. Parasitic: 289 (Peridineae); 306; 323 (*Cephaleuros*); 532; 662; 712; 760; 910; 948; 974 (*Cephaleuros*); 995.

c. Endophytic: 290 (*Cycas*); 314; 322; 330; 359; 438; 483; 493; 622 (*Cycas*); 663 (liverworts); 717 (endophytic Cyanophyta); 971.

d. Epiphytic: 248 (arboreal); 254 (apparatus for studying); 297; 323; 451 (distribution); 641; 644; 662, 712 (epiphyllous); 720; 836; 908; 915; 934 (*Trentepohlia*); 935; 974; 980.

e. Endozoic: 329 (Sponge); 379; 439 (*Zoochlorella*); 489 (in guinea pigs and rabbits); 605 (in Man); 688; 748 (protozoa); 912; 990 (Invertebrates); 991 (corals).

f. Epizoic: 472; 519 (*Anopheles*); 602A; 635 (Sloth); 743, 945 (tortoise).

g. Bacteria: and Other Symbioses: 300; 453, 633, 711, 847 (oxidation ponds); 576 (*Cladophora*); 689; 773 (bacteria and *Volvox*).

4. WATER SANITATION: PATHOGENIC. The ecology and life histories of fresh-water, as well as of marine algae, red tide for example, become involved in problems of an economic nature from the standpoint of health and sanitation. Loss of fish caused by algal blooms is frequently serious. Water-fouling algae, especially blue-greens and the Diatoms spoil water for domestic and indus-

trial use; water supply filters are clogged; domestic animals are killed; recreation sites are ruined. In order to control efficiently or eradicate algae specific identification is usually of value, the life history must be considered, and the chemical nature of the habitat must be determined. This is important because the efficient control of objectionable algae is related to time of year, stages in the life history of the organisms involved or the level of their development. There is a voluminous literature dealing with objectionable algae, their effects and their control. A few selected references are:

a. Algal Control: 146; 161; 178; 184A; 229; 258; 319; 349; 350; 372; 374; 435; 447; 454; 474; 477; 478; 498; 499; 501; 502; 528; 550; 638; 642; 643; 644; 647; 664; 669; 671; 673; 674; 680; 681; 705; 735; 746; 774; 811; 816; 853A; 860; 887; 902; 959; 961.

b. Sanitation and Animal Deaths: 143 (fish); 336 (fish and Dinoflagellatae); 390 (animals); 436 (toxic gases); 462, 463 (fish); 510, 511, 747 (animals); 859 (fish and Dinoflagellatae); 867, 875 (animals).

c. Pollution.

a. Effect of sewage on plankton and other algae: 237; 239; 861; 961.

b. Index Organisms: 601; 723; 724; 901; 933; 961.

c. Oxidation Ponds and Symbiosis of Algae and Bacteria: 453; 633; 711; 847.

d. Biology of Polluted Waters: 238 (zonations); 256 (reconditioning).

e. General Considerations: 897; 898.

5. PERTINENT TAXONOMIC AND PHYLOGENETIC ASPECTS

a. Classification: 209; 211; 416; 417.

b. Phylogeny: 412; 416; 417; 419; 604; 715.

B. Marine Algae

Pertinent works to which reference should be made for the identification of marine algae in ecological studies are listed in a separate section of the bibliography (B).

Ecological studies of the factors which determine or which are related to distribution, zonations and communities, and to life histories and reproductive phases are numerous in the literature.

Concepts have developed from these studies such as: the interrelationships of limiting factors; the relation between rise and fall of water level and zonation; the exposure of and the physical nature of the substrate and the rate of colonization; the physical effects of water movement; light intensity and duration; salinity, and others. Because these are all related in turn to life histories and reproduction a selected number of published works are listed below, including references to culture work which plays an important part in both ecological studies and in investigations of the life cycle of marine algae.

1. CULTURE STUDIES AND LIFE HISTORIES.

a. General: 151 (plankton); 247 (marine algae in fresh water); 285 (phylogeny); 302 (phylogeny of Phaeophyta and Rhodophyta); 327 (life cycles and cytological studies); 358 (life cycles and genetics); 557 (growth rate); 703; (aquaria culture); 714 (in relati to morphology); 821 (plankton); 904 (on Phaeophyta); 914, 944 (general).

b. Genera and Algal Classes: 145 (*Heterochordaria*, Phaeophyta); 184 (Rhodophyta life histories and evolution); 196 (Phaeophyta); 202, 203, 204 (Rhodophyta); 212, 213, 214, 215 (*Enteromorpha*); 253 (*Fucus* and hybridization); 259 (*Antithamnion*); 266 (*Padina*); 267 (*Laminaria*); 285 (Chlorophyta); 292 (Florideae); 333, 334, 335 (Rhodophyta); 354 (*Caulerpa*); 357 (*Laminaria*); 377 (*Cutleria*); 378 (Fucaceae); 381 (*Halicystis*); 384 (Bonnemasoniaceae); 397, 399 (*Cladophora* and *Ulva*); 427 (Phaeophyta); 432 (*Fucus*); 466 (*Acetabularia*); 475 (*Enteromorpha* and *Chaetophora*); 476 (*Codium*); 481 (*Zonaria*); 484 (*Pelagophycus*); 487, 488 (*Cladophora*, meiosis); 491 (*Halicystis*); 492 (*Eisenia*); 494, 495, 496, 497 (*Dictyota*); 508 (Diatoms); 512 (*Sargassum*); 518 (*Caulerpa*); 520 (*Microdictyon*); 542, 543, 544 (Laminariaceae); 558 (*Cystoseira*); 561 (*Asperococcus*); 562 (marine phyla, Isle of Man); 577 (*Derbesia* and *Halicystis*); 585 (*Sargassum*); 590 (*Laminaria*); 591 (Tilopteridaceae); 594 (Phaeophyta); 595 (Rhodophyta); 596 (Chlorophyta); 597, 598 (Ulvaceae); 616 (*Macrocystis*); 617 (*Griffithsia*); 619 (Rhodophyta);

621 (kelps); 686 (*Postelsia* and *Laminaria*); 687 (*Egregia*); 702 (*Fucus*); 713 (*Ectocarpus*); 754 (*Alaria*); 761, 762 (*Enteromorpha*); 770 (*Zanardinia*); 771 (Dictyotaceae); 772 (*Cutleria*); 776 (Diatoms); 795, 796, 797 (Cutleriaceae); 798 (*Halopteris*); 799, 800, 801, 802, 803 (Laminariaceae); 804 (*Dictyosiphon*); 806 (*Phyllaria*); 808 (*Sporochnus*); 809 (*Carpomitra*); 810 (periodicity of life cycles in Phaeophyta); 812 (*Valonia*); 813 (*Ulva*); 822 (Desmarestiaceae); 827 (Siphonales); 829 (Chlorophyta); 830 (cytology Chlorophyta); 831 (*Cladophora*); 832 (Chlorophyta); 833 (*Caulerpa*); 834 (*Codium*); 835 (*Spermothamnion*); 838 (*Saccorhiza*); 854 (Chlorophyta); 856 (*Ulva*); 892, 893, 894 (*Ceramium*); 895 (Rhodophyta); 904 (Phaeophyta); 930 (*Laminaria*); 965, 966, 967, 968 (Dictyotaceae); 969 (*Laminaria* and *Chorda*); 984 (Ulvaceae); 985 (*Polysiphonia*); 986, 987 (*Cutleria* and *Aglaozonia*); 988 (*Zanardinia*); 1000 (*Bryopsis*).

2. ECOLOGICAL FACTORS.

a. General: 171 (light and temperature as biological factors: not particularly related to algae); 282 (methods of surveying); 283 (resume of ecological factors); 530, 531 (terminology of marine ecology); 628 (methods for plankton analyses); 889 (general consideration of ecological factors).

b. Light: 157 (tide pools); 167; 168; 171; 174; 175; 370; 380; 665; 666; 667; 740; 846 (light penetration).

c. Chemical and pH: 157; 160 (Diatoms); 164, 165 (pH); 166, 167 (phosphates and plankton); 310, 311 (nutrients and chemical elements); 380; 382; 455 (plankton); 600; 603; 623 (plankton); 629 (plankton); 699 (chemistry and distribution); 852 (plankton, inshore waters); 889 (salinity and distribution).

d. Biology and Reproduction: 202 (morphology); 203 (morphology and physiology in relation to ecological factors); 247 (adaptation of marine algae to fresh water); 556 (tide pool ecology); 562 (ecology of British algae); 589 (ecology of Swedish coast); 710 (marine algae in fresh water); 868, 869, 870 (ecology of littoral flora).

e. Brackish Water Ecology: 144 (Hawaii); 181, 182 (Phaeophyta in salt marsh); 185 (brackish stream ecology); 216 (Oscillatoriaceae); 260, 261 (salinity and periodicity); 264, 265 (British salt march ecology); 275, 276, 277, 278, 279 (salt marsh ecological factors); 337 (variations in plankton); 396 (Diatoms).

3. DISTRIBUTION.

a. General: 383 (general ecological conditions); 486 (general distribution, especially vertical, including associations with animals); 529 (mapping methods); 545 (littoral ecology); 805 (general distribution of marine algae); 905 (Pacific; Galápagos).

b. Factors Related to Distribution: 174 (light); 180 (mucilage content); 344 (exposure); 373 (tides); 383 (general ecological factors); 433 (pH); 461 (exposure); 506 (temperature); 513, 514 (draught resistance, temperature and other factors); 526, 527, 613, 615 (tide levels); 562 (ecology on Isle of Man); 632 (drifting objects); 654 (general); 842 (temperature); 849 (tide levels).

c. Zonation and Vertical Distribution: 179 (growth of different species); 262 (intertidal); 281 (Australia zonations); 287 (classification of zones); 305 (zones of plant and animal associations); 355 (vertical distribution and tide factors); 432 (vertical distribution of *Fucus*); 480 (intertidal factors); 486 (vertical distribution of associations with animals); 530 (terminology); 612 (zonation terminology); 649 (zonation); 668 (vertical); 850 (zonation in the Antarctic); 868 (intertidal); 874 (intertidal zonation); 977 (zonation in Australia); 997 (zonation in Fucaceae).

d. Geographical Distribution: 158 (chalk cliffs, England); 197 (vertical and horizontal, Naples); 198 (in New Zealand); 217 (zonation in the Faeroes); 218 (mangrove algae of West Indies); 219 (Arctic; North Atlantic); 286 (geographical distribution and continental drift); 315 (European); 338 (geographical); 339 (littoral flora); 356 (Oregon coast); 385, 386 (Guadeloupe); 434 (Antarctic); 448 (Dalmatian coast); 449, 450 (Pacific); 515 (zonations, South Africa); 533 (zonations and distribution

in Iceland); 535 (general observations); 551 (New England); 553 (Norway); 562 (Isle of Man); 581 (Helgoland); 593 (Sweden); 636 (western Europe); 675, 676 (New Zealand); 685 (geographical and geological); 690 (Red Sea); 691 (Egypt); 706, 707 (Pacific); 744 (St. Lawrence estuary); 745 (North Atlantic); 794 (Gascony); 843 (general observations); 850, 851 (zonation, Antarctic); 868, 869, 870, 871, 872 (South Africa); 891 (tropical); 903, 905 (tropical, subtropical); 970 (North Carolina); 976, 977 (Australia).

e. Distribution of Algal Classes: 152 (Diatoms); 179 (various species); 375 (Cyanophyta); 398 (Diatoms); 563 (reproduction of *Fucus*): 839 (Laminariaceae).

1. PERIODICITY. Life history studies are not divorced from periodicity in marine algal floras, nor can periodicity be considered without taking into consideration distribution, especially vertical distribution. Periodicity is of special interest when the life history involves isomorphic forms in the alternation of generations among the macroscopic algae. Investigations often include studies of artificially denuded strata to determine succession and the establishment of communities. Papers which deal with periodicity, and with communities of littoral algae especially are:

a. General: 304 (periodicity and growth, of historical interest); 361 (classification and terminology).

b. Factors Related: 320 (temperature); 592 (temperature); 768 (tides, substrates); 889 (salinity). See also Distribution.

c. Habitats: 192 (tide pool); 220 (denuded strata); 261 (brackish lagoon); 345 (intertidal); 768 (artificial substrates); 890, 899 (coral reefs); 1001 (brackish water, Belgium).

d. Geographical: 195 (communities, Gulf of Marseilles); 284 (communities, New Zealand); 315 (Clare Island); 320, 345 (New Zealand); 360 (Swedish coast): 445 (Isle of Man); 446 (Great Cumbrae); 505, 682 (Puget Sound); 620 (New England); 708 (plants and animals, New Zealand); 766 (Scotland); 850 (Antarctic); 888, 889 (Swedish coast); 1001 (Belgium).

e. Periodicity of Algal Groups and Genera: 485 (Diatoms); 618 (*Dictyota*); 620 (Rhodophyta); 779 (kelps).

f. Plankton: 172 (seasonal changes); 485 (Diatoms); 629 (marine periodicity).

5. SYMBIOTISM. Whereas many marine species are epiphytic and endophytic, some become "parasitic" in the sense that pathological conditions of the host may develop. This condition usually results when superficial endophytes make a deep penetration, causing the destruction of immediately surrounding host cells. Mostly the parasite is at least in part pigmented and not entirely dependent upon the host. Life history studies are relatively few, most accounts dealing with descriptions, morphology, and taxonomy. Likewise there have been but few studies on other types of symbiotism such as mutualism or commensalism among the marine algae. Pertinent papers include:

a. Geographical: 599 (parasitism in the Antarctic); 614 (South Africa); 704, 840, 841 (California); 792 (Greenland).
b. Endophytic: Endozoic: 186 (endophytic, Corallines): 990 (Zooxanthelle and corals).
c. Parasitism: Symbiotism in Genera: 162 (*Streblonema* on *Compsopogon*); 187 (*Mikrosyphar*); 291 (*Sphacelaria*); 331 (*Ceratocolax* and *Phyllophora*); 457 (*Actinococcus* and *Sterrocolax* on *Gymnogongrus* and *Ahnfeltia*); 459A (*Rhodochytrium*); 582 (*Rhododermis*); 583 (*Mikrosyphar*); 775 (*Choreocolax*); 807 (*Polysiphonia*); 858 (*Janczewskia*); 885 (*Harveyella*).
d. Parasitism in Algal Divisions: 365 (Florideae); 457 (Rhodophyta); 614 (Chlorophyta, Phaeophyta); 704 (Rhodophyta); 792 (Chlorophyta); 793 (Phaeophyta); 840 (Rhodophyta); 841 (Florideae); 844 (Rhodophyta).

6. ECONOMICS: 332 (*Chondrus* in Britain); 504 (seaweeds on Atlantic coast); 763 (potash); 926, 927, 928 (Agar, carageenin, alginic acid, iodine, potash).

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Presented in three sections but with the entries numbered consecutively throughout

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B. General Taxonomic References for Marine Algae.

C. Ecology and Life History References for Marine and Fresh-water Algae.

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